

# DISCOVERY OF RADIO EMISSION FROM THE TIGHT M8 BINARY: LP 349-25

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## ABSTRACT

We present radio observations of 8 ultracool dwarfs with a narrow spectral type range (M8-M9.5) using the Very Large Array at 8.5 GHz. Only the tight M8 binary LP 349-25 was detected. LP 349-25 is the tenth ultracool dwarf system detected in radio and its trigonometric parallax  $\pi = 67.6$  mas, recently measured by Gatewood et al., makes it the furthest ultracool system detected by the Very Large Array to date, and the most radio-luminous outside of obvious flaring activity or variability. With a separation of only 1.8 AU, masses of the components of LP 349-25 can be measured precisely without any theoretical assumptions (Forveille et al.), allowing us to clarify their fully-convective status and hence the kind of magnetic dynamo in these components which may play an important role to explain our detection of radio emission from these objects. This also makes LP 349-25 an excellent target for further studies with better constraints on the correlations between X-ray, radio emission and stellar parameters such as mass, age, temperature, and luminosity in ultracool dwarfs.

*Subject headings:* radio continuum: stars — stars: activity — stars: coronae — stars: low mass, brown dwarfs — stars: individual (LP 349-25)

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## 1. INTRODUCTION

Main sequence stars are expected to be fully convective if their mass lies below a certain value, about  $0.3\text{--}0.4 M_{\odot}$  (M3–M4 spectral types), as suggested by standard models; this probably shifts toward lower masses ( $0.1\text{--}0.2 M_{\odot}$ ) due to the influence of the magnetic field (Mullan & MacDonald 2001). In fully convective stars, a turbulent dynamo that differs from the shell dynamo at work in partly convective Sun-like stars has been proposed to take place (Durney et al. 1993; Dobler et al. 2006; Chabrier & Küker 2006). However, some recent observations (Donati et al. 2006) have not supported such theoretical models. On one side, the model of Chabrier & Küker (2006) predicts: (1) weak surface differential rotation, in agreement with the observations of Donati et al.; (2) non-axisymmetric large scale fields, in contradiction with these observations. On the other side, the model of Dobler et al. (2006) concludes: (1) large scale axisymmetric fields, in agreement with the observations; (2) significant surface differential rotation, in contradiction with the observations. Therefore understanding how the magnetic field is generated in the fully convective stars and what the field properties are is clearly important.

The atmospheres of such ultracool, very low mass stars are predominantly cool, dense, and highly neutral, apparently precluding the build-up of magnetic stresses thought to provide magnetic heating. Yet, detections of observational signatures commonly associated with magnetic activity in Sun-like and fully convective stars (Liebert et al. 2003; Berger et al. 2001; Stelzer et al. 2006) suggest that the production mechanism is the same or nearly the same in very low mass stars as for low mass and Sun-like stars. Further study of the X-ray emissions (Neuhäuser et al. 1999; Stelzer et al. 2006) and  $H\alpha$  emissions (Gizis et al. 2000; Mohanty & Basri 2003) is one way to delimit the properties of magnetic heating in very low mass stars and indirectly investigate the influence of the magnetic field. Recent detections and studies of radio emission from ultracool dwarfs (Berger et al. 2001; Krishnamurthi et al. 1999; Berger 2002; Burgasser & Putman 2005; Blank 2004; Berger et al. 2005; Audard et al. 2005; Osten et al. 2006; Osten & Jayawardhana 2006; Berger 2006; Hallinan et al. 2006) also offer us another important approach to understand the properties of magnetic fields in the fully convective stars, as the magnetic field is likely intimately involved in the production mechanism of the radio radiation from these objects.

In this paper, we present our radio observation of a sample of 8 ultracool dwarfs and the detection of the M8 binary LP 349-25 using the Very Large Array. In § 2 we present the observation and the data reduction, the properties of the radio emission from LP 349-25 are given in § 3, we discuss radio emission from LP 349-25 particularly and its radio mechanism in § 4.

## 2. SAMPLE, OBSERVATION AND DATA REDUCTION

### 2.1. Sample

We selected a sample of nearby ultracool field dwarfs with spectral types ranging over a narrow band of M8–L0 since 5 of 9 ultracool dwarfs detected at radio wavelengths are M8–M9.5 dwarfs, giving a significant fraction of  $\sim 56\%$  (see Table 1 in Berger 2006 and references therein). The rotational velocities of the stars range from 4 to 35 km s $^{-1}$ , and the  $H\alpha$  equivalent width ranges from 0 to 21 Å. Some known binary systems are also added, including the new tight M8 binary LP 349-25 whose binary status was recently reported by Forveille et al. (2005).

In this paper, we present our radio observation results of 8 of these dwarfs. Their properties are listed in Table 1.

### 2.2. Observations and data reduction

We observed the 8 dwarfs from 2005 December 22 to 2006 January 02 with the NRAO Very Large Array (VLA)<sup>1</sup> when the array was the D configuration, except the observation of 2M 0140+27 in DnC, at 8.5 GHz (3.6 cm) using the standard continuum mode with  $2 \times 50$  MHz contiguous bands. The flux density calibrators were 3C 48, 3C 147, and 3C 286 and the phase calibrators were selected to be within 10° of the targets. The data was reduced and analyzed with the Astronomical Image Processing System (AIPS). Only LP 349-25 was detected at the observed frequency of 8.5 GHz (Fig. 1). In order to examine the emission from this object, we subtracted the visibilities of other radio sources in the field, and re-imaged the visibility dataset. We extracted the position and flux of the source in total intensity, and made an image of the dataset in circular polarization (Stokes V). In addition, we investigated the time variation of the source using the task DFTPL within AIPS.

### 2.3. Analysis

Table 1 gives the flux and upper limits for the detections/non-detections, respectively. The position of the radio source near the center in the map of the field around LP 349-25 coincides with the expected position of LP 349-25 at the epoch of our observations (2005.967)

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<sup>1</sup> The NRAO is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

with its proper motion included ( $\mu_{\text{RA}} = 0.408 \text{ arcsec yr}^{-1}$ ,  $\mu_{\text{DE}} = -0.174 \text{ arcsec yr}^{-1}$ , Lépine 2005). We therefore conclude that the detected radio emission is from LP 349-25. Our initial examination of maps made in total intensity (Stokes I) and circular polarization (Stokes V) show the existence of a weak source in the Stokes V map near this same position. Further investigation, however, reveals that the location of the source in the Stokes V map is offset with respect to the position of the source in the Stokes I map by  $\approx 10$  arcseconds. The right (RCP) and left (LCP) circularly polarized primary beams of the VLA are separated by about 6% of the half-width at half maximum of the antenna beam<sup>2</sup>. This gives rise to a phenomenon known as “beamsquint” (Cotton 1999), and for observations at 8.5 GHz the magnitude of the offset is 10.3 arcsec. This makes the detection of circular polarization intrinsic to the source suspect. Finally, re-imaging of this field in Stokes V after subtracting the visibilities in total intensity produces a lower significance ( $< 3\sigma$ ) of the source. Based on the fluctuations in the Stokes V image, we deduce a  $3\sigma$  upper limit of 48  $\mu\text{Jy}$ , or a circular polarization percentage  $< 13\%$ .

The total extent of the observations of LP 349-25 was only  $\sim 1.7$  hours, precluding the possibility of searching for rotational modulations, as this would correspond to one rotation period only for very rapidly rotating objects (e.g. TVLM 513-46546; Osten et al. 2006; Hallinan et al. 2006). We extracted light curves of total intensity from the visibility dataset using time bins of 300 and 60 seconds to search for short-time scale transient brightenings. No obvious evidence of flare variability presented itself on visual inspection of either light curve. Using the one-sided Kolmogorov-Smirnov statistic, we tried to see if we could reject the null hypothesis that the fluxes are distributed uniformly in time and thereby establish evidence for variability. We compared the cumulative distribution function of the fluxes to that of a uniform distribution in time, and conclude that the data are consistent with being drawn from a uniform distribution of events with KS statistics of 0.05 and 0.01 for the 300 and 60 second time binnings, respectively. The KS probabilities are unity in both cases, thus we find no evidence for variability.

### 3. PROPERTIES OF THE RADIO EMISSION FROM LP 349-25

The flux detected from LP 349-25 together with the parallax measurement of 67.6 mas (Gatewood et al. 2005) imply a radio luminosity of  $9.6 \times 10^{13} \text{ erg s}^{-1} \text{ Hz}^{-1}$ . This is  $\approx 3$  times larger than the steady luminosities of previously detected single very low mass dwarfs with similar spectral types (M8–M9). The makeup of the binary system in LP 349-25 is likely

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<sup>2</sup><http://www.vla.nrao.edu/astro/guides/vlas/current/node34.html>

M7.5V+M8.5V or M8V+M9V (according to Forveille et al. 2005), and thus if the two components are equal contributors to the radio flux the radio luminosity of each dwarf would be comparable to or slightly brighter than the steady flux levels of the brightest apparently single dwarf previously detected. The projected separation of the binary is  $0.12''$  or  $1.78$  AU at the distance of  $14.8$  pc, derived from its trigonometric parallax measured recently (Gatewood et al. 2005). The beam size of the image from our D array observations is  $9.2'' \times 8.0''$  (major axis  $\times$  minor axis), with a position angle of  $76^\circ$ , thus we cannot spatially resolve the two components.

With only one observed frequency of  $8.5$  GHz, we cannot constrain an emission mechanism. Previous papers have discussed two mechanisms: gyrosynchrotron emission from a population of mildly relativistic accelerated particles (Berger 2002, 2006; Burgasser & Putman 2005; Osten et al. 2006), and cyclotron maser emission (Hallinan et al. 2006). The brightness temperature of the emission is fundamental to constraining the emission mechanism, but with two dwarfs both being potential sources of the radiation, there are two unknowns in converting flux to brightness temperature: The fraction of the total flux which each component contributes, and the size of the emitting region (being possibly different for each dwarf). We consider two simplifying cases: (1) each dwarf contributes half the observed flux, with characteristic length scale the radius of the dwarf (where the radius is  $\approx 0.1 R_\odot$ ) as suggested by the previous observations (Leto et al. 2000; Berger 2006); (2) one dwarf contributes all of the emission, with length scale one tenth the dwarf radius as observed in a few M dwarfs (Lang et al. 1983; Bastian et al. 1990). Application of the relationship between brightness temperature, frequency, flux density, and source size (Leto et al. 2000),

$$T_b = \frac{4.33 \times 10^5 S_{\mu\text{Jy}}}{\nu_{\text{GHz}}^2 \theta_{\text{mas}}^2} \text{K} \quad (1)$$

where  $S_{\mu\text{Jy}}$  is the source flux in  $\mu\text{Jy}$ ,  $\nu_{\text{GHz}}$  is the observing frequency in GHz, and  $\theta_{\text{mas}}$  is the angular size of the source in mas, yields for the first case  $T_b = 1.1 \times 10^9$  K, and in the second case  $T_b = 2.2 \times 10^{11}$  K. The high brightness temperatures indicate that the emission is nonthermal and could be consistent with gyrosynchrotron emission (Dulk 1985). One should note that larger size scales reduce the estimated brightness temperatures. In the second case, with  $T_b \sim 10^{11}$  K a coherent mechanism, such as cyclotron maser emission is also applicable. Such a mechanism has been suggested by Hallinan et al. (2006) to account for the periodic variation of flux density and circular polarization in two other dwarfs. Hallinan et al. (2006) noted that the unmodulated flux of their target, TVLM 513-46546, could be attributable to gyrosynchrotron emission with undetected circular polarization. Clearly, more observations of LP 349-25 are needed to determine its characteristics better.

#### 4. DISCUSSION

Our sample of 8 late-M dwarfs with spectral types ranging from M8.0 to M9.5 produced only one detection, that of a binary consistent with two M8 dwarfs. Including the objects in our survey with previous reports on late M-T dwarfs (Krishnamurthi et al. 1999; Berger et al. 2001; Berger 2002, 2006; Burgasser & Putman 2005; Audard et al. 2005; Osten & Jayawardhana 2006), the fraction of late-M and brown dwarfs detected at radio wavelengths is  $\sim 10\%$  so far (see Table 1 in Berger 2006 and references therein, Osten & Jayawardhana 2006). Interestingly, over a narrower range of spectral type,  $\sim M8 \leq SpT \leq M9.5$  a larger fraction, 18%, of objects have been detected at radio wavelengths, including our sample.

Berger (2002) suggested that rotation may play a role in influencing which objects are detected at radio wavelengths, by noting that the few objects with radio detections were among those with the largest values of  $v \sin i$ . The relationship between rotation and the existence of large-scale magnetic fields, which may be necessary to influence the production of radio emission, has been suggested for fully convective stars by Phan-Bao et al. (2006), based on measurements of longitudinal magnetic field strengths in the active dM3.5e star EV Lac ( $v \sin i = 4.5 \text{ km s}^{-1}$ ) and absence in the slower rotator dM5.5 HH And ( $v \sin i < 1.2 \text{ km s}^{-1}$ ). The fact that none of the fast rotators in our sample ( $7 \leq v \sin i \leq 12 \text{ km s}^{-1}$ ) provided radio detections suggests that  $v \sin i$  is not the dominant factor controlling the production of detectable levels of radio emission. Only the binary LP 349-25 was detected but unfortunately the rotational velocities of its components have not been measured so far. Thus, the correlation between radio emission and rotation is still unclear.

The ambiguous relationship between rotation and radio emission is strengthened upon considering the field M stars VB 8 and LHS 3003 (both spectral type M8), which have similar rotational velocities ( $8 \text{ km s}^{-1}$  for VB 8 and  $9 \text{ km s}^{-1}$  for LHS 3003), and are located at  $d \sim 6.5 \text{ pc}$ . Despite the similarities in spectral type,  $v \sin i$ , and distance (which produces similar sensitivities), only LHS 3003 has shown radio quiescent emission (Burgasser & Putman 2005; Krishnamurthi et al. 1999). One possible explanation is that they were observed at different radio frequencies: Krishnamurthi et al. (1999) observed VB 8 at 8.5 GHz and Burgasser & Putman (2005) observed LHS 3003 at frequencies of 4.8 and 8.6 GHz but they only detected the star at 4.8 GHz. This might suggest that the spectral peak of radio emission from ultracool and brown dwarfs is closer to 4.8 GHz rather than 8.5 GHz, as discussed in Osten et al. (2006). Another possible explanation lies in the bias that inclination can introduce in estimating rotation rates from  $v \sin i$ . Photometric periods combined with spectroscopic rotation velocities have the potential to nail down this discrepancy (e.g. Bailer-Jones 2004).

There is no explicit dependence between either emission mechanism proposed so far for

radio emission from very low mass dwarfs and rotation. For two cases where radio emission has been detected and rotational modulation of the emission has been determined, Hallinan et al. (2006) proposed a model whereby a large scale dipole or multipole with magnetic field strength of a few kG at the stellar surface can produce cyclotron maser emission in regions where the strong-field condition  $\nu_p/\nu_B \leq 1$  is satisfied, where  $\nu_p$  is the plasma frequency ( $\approx 9000\sqrt{n_e}$  Hz) and  $\nu_B$  is the gyro-frequency ( $= 2.8 \times 10^6 B(\text{G})$  Hz); i.e. in regions of low electron density and high magnetic field strength. The recent detection of a strong and large-scale axisymmetric magnetic field on a rapidly rotating M4 dwarf (V374 Peg,  $v \sin i = 36 \text{ km s}^{-1}$ ) bolsters the suggestion of a link between large-scale fields, rapid rotation, and detectable levels of varying radio emission, but provides only a post hoc explanation for why some objects are detected at radio wavelengths. Clearly, a detailed investigation of those objects which do show evidence of radio emission is needed, along with suitable samples of objects with similar properties but lacking in radio detections, to tease out any controlling parameters.

So far, there are no clear correlations between radio emission from ultracool and brown dwarfs and their properties such as rotation, spectral types, and chromospheric activity; and radio emission mechanisms are possibly gyrosynchrotron or coherent electron cyclotron maser emission.

## 5. CONCLUSION

We present our radio observations of a sample of 8 late-M dwarfs, with spectral types ranging over a narrow band of M8.0–M9.5. Only one of them has been detected, the M8 binary LP 349-35. We have observed LP 349-25 at only 8.5 GHz, thus incoherent gyrosynchrotron or coherent electron cyclotron maser emission could be applicable. Observation of multiple radio frequencies will clarify the radio emission mechanism of the binary, and measurement of  $v \sin i$  of each component will also be required to test whether any correlation with rotation is implied by this radio detection. The lack of detections of the fast rotators in our sample suggest a murky picture of the relationship between radio emission and rotation (as measured by  $v \sin i$ ). Finally, with a separation of only 1.8 AU, derived from an angular separation of  $0.12''$  and  $\pi = 67.6$  mas (Forveille et al. 2005; Gatewood et al. 2005), dynamical masses of each component of LP 349-25 are under measurement (T. Forveille, private communication). As the masses of the components of LP 349-25 can be measured precisely without any theoretical assumptions, this will therefore allow us to clarify their fully-convective status (e.g., 0.1–0.2  $M_\odot$ , Mullan & MacDonald 2001), and hence the kind of magnetic dynamo in these ultracool dwarf components which may play an important role

to explain our detection of radio emission from these objects. This also makes the system an excellent target for further studies with better constraints on the correlations between X-ray, radio emission and stellar parameters such as mass, age, temperature, and luminosity in ultracool dwarfs.

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Table 1: THE SAMPLE OF 8 LATE-M DWARF STARS

Name	$\alpha^a$	$\delta^a$	SpT	$d$ (pc)	$F_{\nu,R}$ ( $\mu$ Jy)	$v \sin i$ (km s $^{-1}$ )	$H\alpha$ EW ( $\text{\AA}$ )
LP 349-25AB	00 27 55.93	+22 19 32.8	M8.0 <sup>b</sup>	15	365 $\pm$ 16	...	...
2M 0109+29	01 09 21.70	+29 49 25.6	M9.5	19	<54	7	0.6
2M 0140+27	01 40 02.64	+27 01 50.6	M8.5	19	<20	6.5	3.0
2M 0149+29	01 49 08.96	+29 56 13.2	M9.5	17	<140	12	5.5
2M 0810+14	08 10 58.65	+14 20 39.1	M9.0	20	<39	11	12.3
2M 1421+18	14 21 31.45	+18 27 40.8	M9.5	20	<42	...	3.6
2M 1627+81	16 27 27.94	+81 05 07.6	M9.0	21	<60	...	6.1
2M 1707+64	17 07 18.31	+64 39 33.1	M9.0	17	<60	...	9.8

<sup>a</sup> Right ascension and declination from the 2MASS catalogue

<sup>b</sup> LP 349-25A: M7.5/M8.0; LP 349-25B: M8.5/M9.0

NOTE.— References for source properties: Forveille et al. (2005); Gizis et al. (2000); Gatewood et al. (2005); Reid et al. (2002);

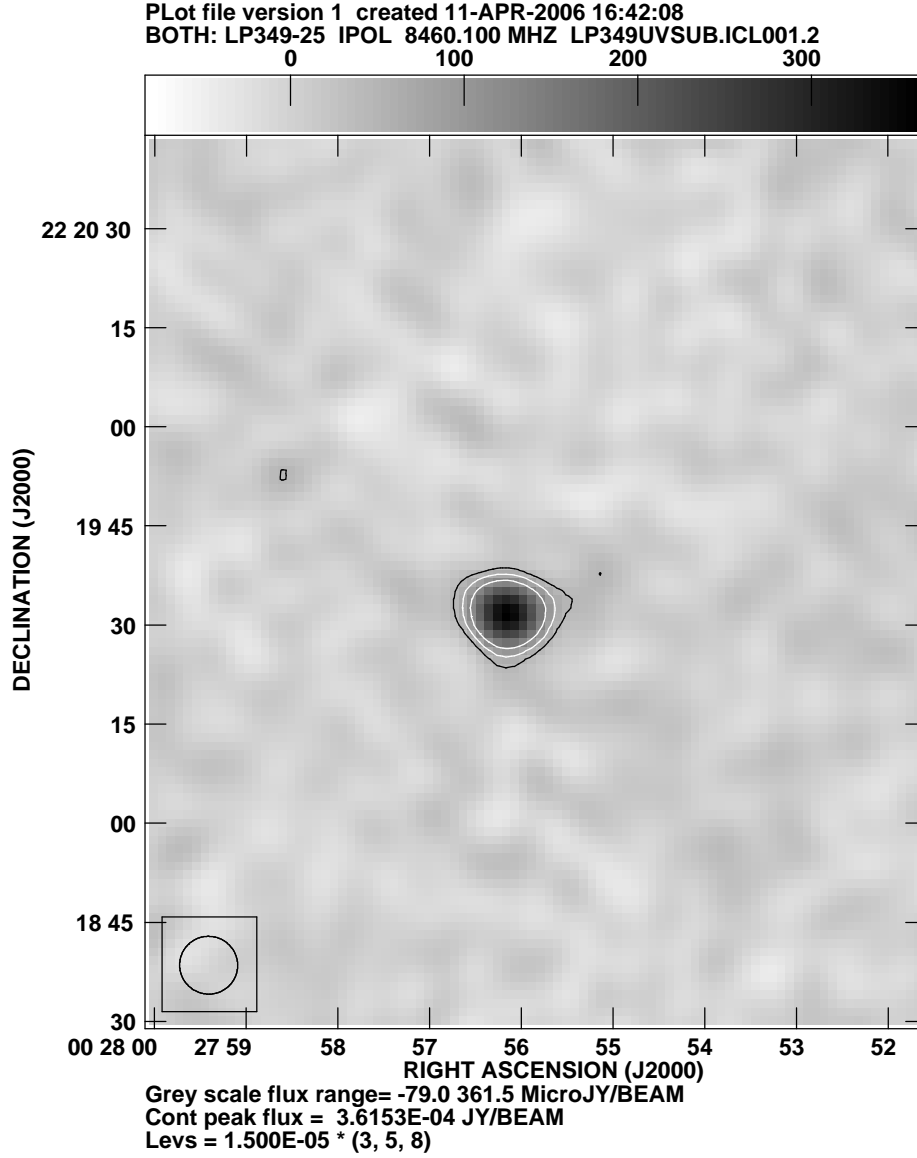


Fig. 1.— A VLA map of the LP 349-25 field at 8.5 GHz. The grey scale image is the map of total intensity. Contours of total intensity are overplotted as multiples of the  $1\sigma$  flux uncertainty; the 3, 5 and 8  $\sigma$  contour levels are shown. The beam size is also shown at the bottom left of the map.